Land Surface Modelling Studies in Support of AQUA AMSR-E Validation

Year 3 Progress Report

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1. INTRODUCTION

The AMSR-E validation plan includes an evaluation of the derived level-2 and level-3 soil moisture product to assure that AMSR-E provides products that are both accurate and appropriate for hydrological modeling. The investigation focuses on the retrieval of soil moisture over regional to continental scales, understanding the heterogeneity at various spatial scales for validation and the validation of AMSR-E soil moisture products with data at different depths from in-situ measurements and hydrological modeling.

The project is structured around four tasks, as follows: (1) Test and extend the land surface microwave emission model (LSMEM), which was developed for the retrieval of soil moisture from passive microwave sensors (see Gao et al., 2004). (2) Produce real-time AMSR-E simulated science data products, which will be carried out at resolutions ranging from 1km (MODIS scale) to 25 km (AMSR-E scale) to understand the scaling and heterogeneity issues. (3) Compare AMSR-E brightness temperatures and retrieved soil moisture to other microwave instruments like TMI and SMMR so to help the AMSR-E science team better understand the spatial and temporal variability of these brightness temperatures, and therefore help to better interpret the AMSR-E data. (4) Test the AMSR-E validation plans through hydrologic model simulations. This will be done by comparing soil moisture data from in-situ measurements, air borne remote sensing, and hydrological modeling, and will provide critical insight into the validation sampling plans. Overall, these tasks will involve understanding the sub-grid heterogeneity and how to use hydrological modeling to upscale the in-situ point data to a product comparable with AMSR-E 25km soil moisture product, as well as the possible problem due to the different depths represented by different data sources.

2. ACTIVITIES DURING THE LAST YEAR

During this year, research at Princeton focused in four areas: (i) completing the task using LSMEM to estimate soil moisture from the airborne ESTAR observations during SGP99 (Task 1); (ii) retrieving AMSR-E soil moisture from the Soil Moisture Experiment (SMEX02) AMSR-E field validation campaign in Iowa (Tasks 1 and 4); (iii) comparing AMSR-E and TMI soil moisture retrievals over the Southern Great Plains using LSMEM (Task 2); and (iv) initiate joint validation activities in Australia.

2.1 Using LSMEM to Estimate Soil Moisture from ESTAR Observations During SGP99

The SGP99 data provided a comprehensive data set for evaluating microwave remote sensing of soil moisture algorithms that involve complex physical properties of soils and vegetation. LSMEM is used to retrieve soil moisture from brightness temperatures collected by the airborne ESTAR L-band radiometer. The retrieved soil moisture had an average RMS error over the study sites of 2.1% volumetric soil moisture. This work was published in Gao et al. (2004). The algorithm is being used to retrieve soil moisture from TRMM Microwave Imager and AMSR-E.

2.2 Soil Moisture Experiment, Iowa, USA 2002

AMSR-E 25km brightness temperatures were resample to a 1/8th degree grid using a simple nearest neighbour interpolation scheme. The re-sampling of the data was necessary in order to integrate the brightness temperature measurements into our existing analysis framework. Data were analysed to coincide with the SMEX02 campaign, which extended from June 25 – July 12. AMSR-E retrievals start from June 19, the earliest data available from the Marshall Space Flight Centre archive (ariel.msfc.nasa.gov), and continue until the end of July.

A detailed Geographical Information System (GIS) was developed for Iowa, focusing on the study region. Table 1 details the contents of this developing data inventory.

Table 1. Inventory of GIS compiled for study of AMSR-E validation (IA).

Name	Description	Source
DEM	90m digital elevation model of Iowa	USGS 90m
Stream Network	1:100,000 hydrography network provides a network of rivers and streams, including intermittent streams, ditches, and canals.	USDA/NRCS - National Cartography & Geospatial Center
Ancillary Data	Site information, spatial extents, sampling locations, instrument locations etc…	SMEX-02 data distribution at NSIDC
Vegetation	250m NDVI and 1km LAI data	Derived from MODIS Land Surface Products
HYDRO1K	Compound Topographic Index, Slope, Aspect, Drainage Basins etc…	Land Process DAAC

2.2.1. AMSR-E Soil Moisture Comparison with the Polarimetric Scanning Radiometer (PSR)

The PSR, an airborne microwave imaging radiometer operated by the NOAA environmental Technology Laboratory (Piepmeier and Gasiewski, 2001), was flown aboard the NASA P-3 aircraft for the purpose of obtaining polarimetric microwave emission. The PSR data provides an excellent intermediary source of validation information between the AMSR-E pixel and the ground based measurement, and provides the only feasible option to comparing predictions with a reasonable spatial equivalence to the AMSR-E footprint and measurement characteristics. Data from the PSR was supplied in an irregularly spaced grid at a nominal resolution of 800m, with soil moisture predictions calculated independently by the USDA (pers. com. Dr Rajat Bindlish). The PSR measurements supplied ten complete moisture maps of the region, encompassing an area of approximately 0.7°x1° (see Figure 1).

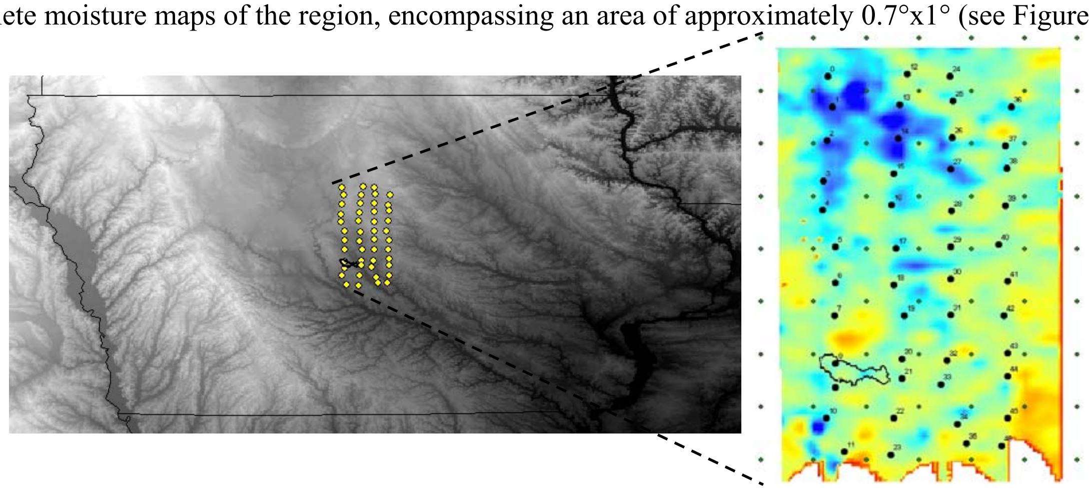
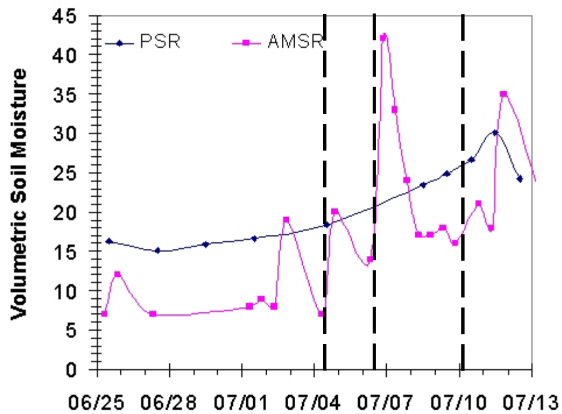


Figure 1. DEM of Iowa with the regional sampling locations across the SMEX domain. Inset is a sample image of the PSR soil moisture measurement at supplied resolution (~800m).

To examine these scale effects of the PSR data and to allow a more equivalent comparison with the AMSR-E footprint, the PSR moisture measurements were resampled at a variety of resolutions from 1km to 25km in order to assess the consistency of sub-pixel statistical variation. The analysis was divided broadly into dry and wet periods, corresponding to the marked meteorological periods during SMEX 02. As expected, the results indicate a preservation of the statistical features across scales, retaining many of the visual features evident in the highest resolution imagery even at larger scales. PSR data resample to 1/8th degree was compared to the corresponding AMSR-E retrieved values for all available data, with results presented in Figure 2. There appears to be a consistent bias between the PSR and AMSR-E imagery, with PSR values generally higher than the corresponding AMSR-E predictions. The general trend however is well reflected, although AMSR-E responds more sharply to incident precipitation which occurred on the 4, 6 and 10 July. It should be noted that the PSR soil moisture retrievals are determined from C-Band measurements (6.9GHz) whereas the AMSR-E retrievals are based on X-Band measurements (10.7 GHZ).



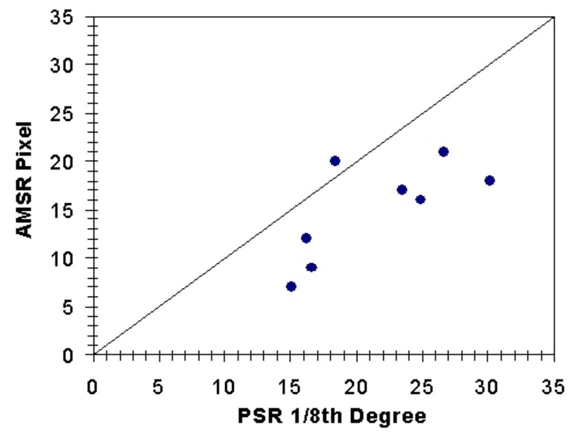


Figure 2. PSR and AMSR-E responses during the SMEX 02 campaign (left) and coincident PSR and AMSR-E estimates. Dashed lines indicate the precipitation events - more clearly represented in Figure 3 below.

Areal imagery derived from the PSR and AMSR-E soil moisture retrievals (not presented) shows a great deal of agreement between the PSR and AMSR-E, and indicates that some confidence can be placed in the remotely sensed retrievals, even at apparently coarse resolutions. The results of the AMSR-E analysis indicates that there is some utility in assimilating these predictions into the LDAS framework to improve the representation of the soil moisture dynamics.

2.2.2. AMSR-E Comparisons with Ground Based in-situ SCAN Network

i. Ames SCAN site (42°01’, 93°44’) http://www.wcc.nrcs.usda.gov/scan/

The Soil Climate Analysis Network (SCAN) site offers a continuous and consistent data set to the theta probes used during the SMEX campaign. The AMES SCAN site has been in operation since 9/23/2001 and provides continuous hourly data measured at a number of depths by a Stevens Vitel Hydra Probe. Data from the SCAN site were extracted and compared with a collocated AMSR-E pixel (the same pixel used in the proceeding watershed analysis). Figure 3 illustrates the resulting SCAN response at 2 inches (~50mm) and the measured precipitation at the site, along with the retrieved AMSR-E soil moisture. As can be seen, there is excellent agreement between the data for the period June 20-July 4, with the data reflecting the drying down after the rain events earlier in the month. There is a fairly constant offset during this period of approximately 10 %vol/vol, a result of the relative depths of measurement (AMSR-E provides a near-surface soil measure). The onset of the rain events on the 4, 6 and 10 July incite a marked spike in both responses, gradually drying down again towards the end of the month and resuming a positive bias. There are interesting diurnal effects evident in the AMSR-E response, with PM (2pm) values generally exceeding the AM (2am) estimates during the same diurnal cycle. Overall, the AMSR-E retrievals, although obviously influenced by pixel-to-point scale and measurement disparities, reflects well the trends observed in the SCAN response.

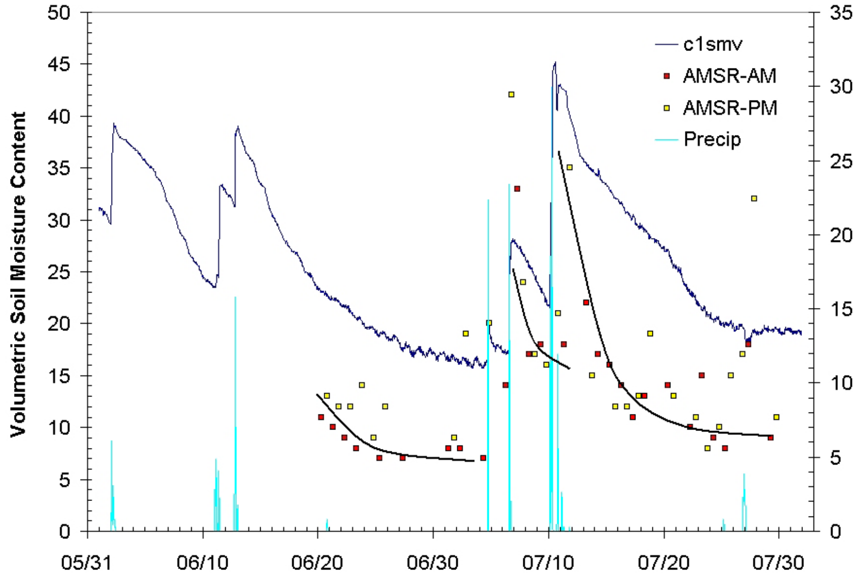


Figure 3. Profile soil moisture (2”) as measured at the SCAN site during the SMEX 02 study period. AMSR-E retrievals corresponding to the SCAN site are separated into AM and PM overpasses. Precipitation at the SCAN site is also plotted. Curves are for visual reference only.

ii. Regional Sampling over the SMEX Domain

The regional soil moisture sampling during SMEX was designed to capture the broader scale soil moisture pattern at the satellite footprint scale, and incorporated 46 unique sites distributed over the SMEX domain. Of these, Site 8 and Site 9 corresponded to positions within the area of the watershed sampling at Walnut Creek and within one of the re-sampled AMSR-E pixels. The grid of individual sample sites covers a domain of approximately 50 km by 100 km (2 by 4 AMSR-E pixels) and measurement sampling was timed to coincide with the afternoon AMSR-E overpass.

Results for the regional analysis are shown in Figure 4, showing the average volumetric moisture contents at Site 8 and Site 9 along with the regional mean, as measured using a theta probe. The bars at each of the sample days indicates the total standard deviation at the site(s). Figure 4(c,d) also detail the AMSR-E distribution for the equivalent area encompassing Site 8 and Site 9 and the entire region. The general patterns are well represented across the regional and site averages. The stability during the dryer periods preceding July 4 is clearly shown in the AMSR-E responses. A significant amount of noise is evident in the AMSR-E regional response during the period July 7-14, corresponding to the wet periods of the field campaign. Interestingly, this seems to be in contradiction to the theta probe samples, which show minimal daily variations in the standard deviations.

iii. Point Scale Measurements in Walnut Creek

During the SMEX watershed sampling, over 4,500 unique theta probe samples were collected, allowing a detailed accounting of the soil moisture variability within this study catchment. Of these, 19 (from 33 sites) were within the resampled AMSR-E footprint, allowing a truly spatially representative *in-situ* soil moisture average to be compared with the model retrieved value. The distribution of sites across the catchment (Figure 5) was intended to effectively capture the level of spatial heterogeneity of the point scale soil moisture. AMSR-E retrievals were compared with the areal mean of the *average* soil moisture recorded for each site. As can be seen, there is a gradual increase in the catchment average soil moisture as the field campaign progresses, consistent with the precipitation records for the region and reflected in the imagery derived from the PSR measurements (see Figure 6). The equivalence with the AMSR-E pixel is excellent, particularly given the scale disparity between the two approaches and also the different sampling depths of the techniques (6cm for theta probe). Although only eight samples were available to be compared, consistent agreement between the two measurements is evident. The mean absolute error between the samples is 2.64 %vol/vol with a correlation coefficient of 0.87.

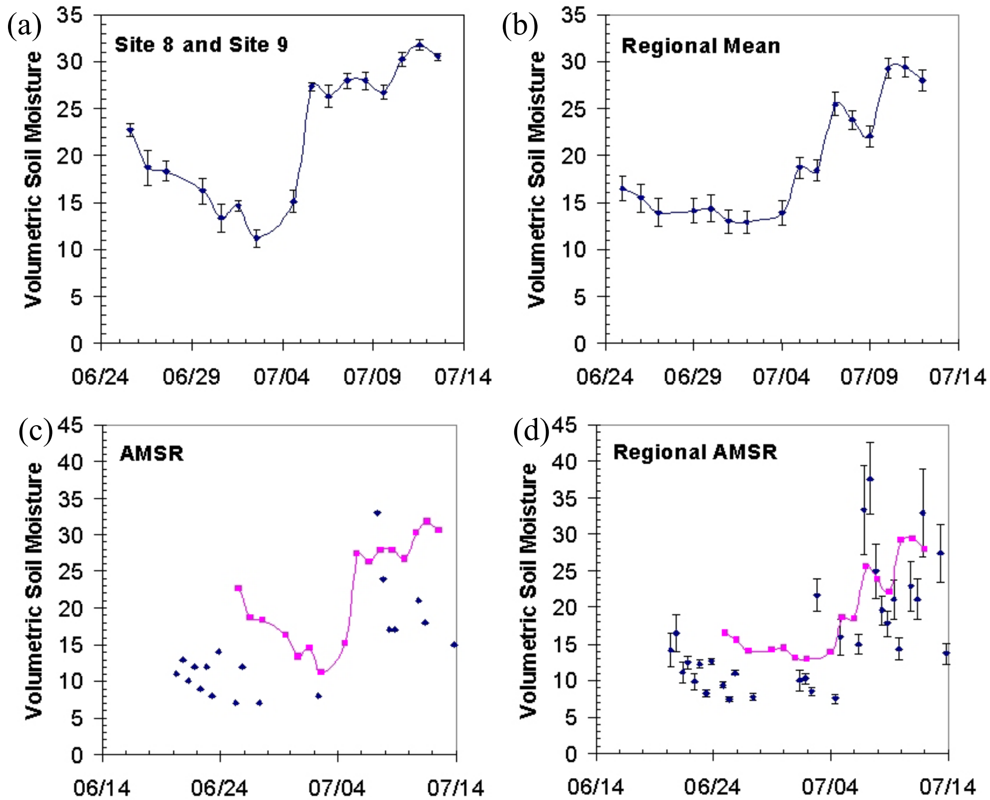


Figure 4. Regional theta probe sampling results for the (a) average of Site 8 and 9 and (b) entire region. Bars depict the standard deviation of measurements for each day. The corresponding single pixel AMSR-E retrievals are shown in (c), along with the regional average of the AMSR-E pixels (d) and their daily regional standard deviation. The solid lines repeat the theta probe samples from (a) and (b).

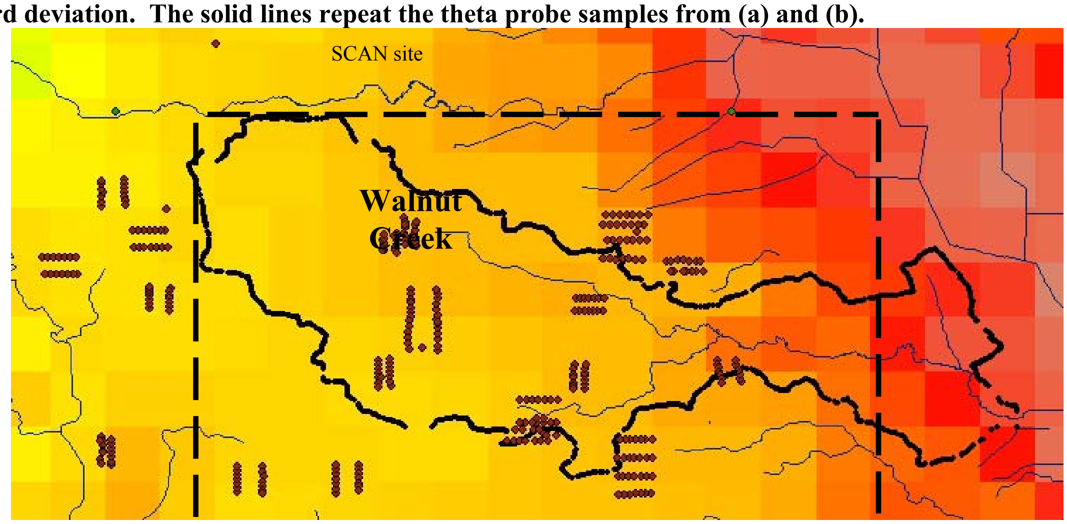


Figure 5. Sampling strategy measurements taken over the Walnut Creek site. Underlying image is a DEM which indicates a 60m relief from catchment boundary to outlet. The sampling regime composes approximately 65% of a resampled (1/8°) AMSR-E pixel (dashed line).

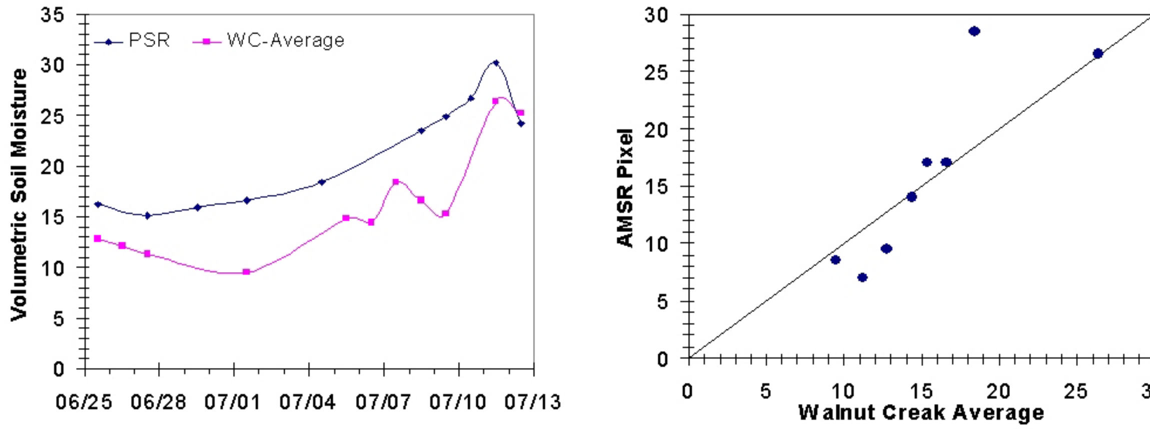


Figure 6. Comparison of the *in-situ* theta-probe measurements with the PSR derived measurements, and a scatter plot of the retrieved AMSR-E predictions and the catchment average theta-probe soil moisture.

2.3 Oklahoma Mesonet Data and TRMM-TMI Comparisons

2.3.1. AMSR-E and TRMM-TMI Soil Moisture Retrieval

Soil moisture values were retrieved from AMSR-E 10.7 GHz brightness temperatures in Oklahoma from Jun. 2002 to Dec. 2003. These products were compared with those from TRMM Microwave Imager (TMI), the Oklahoma mesonet, and the LDAS-VIC model. The usefulness of AMSR-E 6.7GHz (C band) is questionable because of RFI. Therefore the 10.7 GHz (X band) may be the only frequency available for soil moisture estimation. It is therefore useful to inter-compare soil moisture estimates from the two instruments, especially since we have a good understanding the accuracy of the TMI values from our 5-yr (1998-2002) retrievals (Gao *et al.*, 2003). To examine how the two datasets behave over longer time period and larger scales, the pixel values over the OK mesonet sites were averaged and plotted in Figure 7, resulting in a RMSE of approximately 3%.

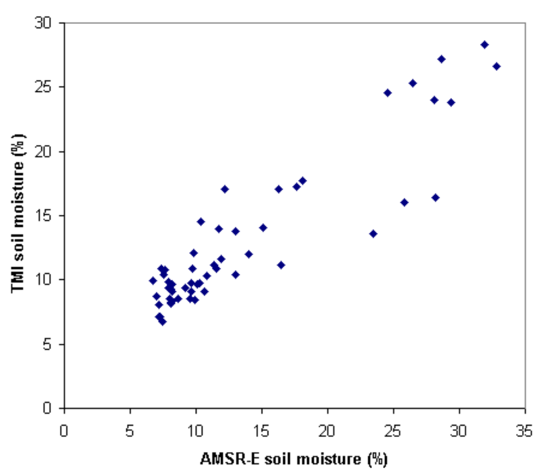


Figure 7. Scatter plot of averaged AMSR-E and TMI soil moisture over Mesonet sites from Jul. 2002 to Nov. 2002.

2.3.2. Spatial Heterogeneity Analysis for Oklahoma

Studies of sub-grid heterogeneity are aimed towards improving the AMSR-E validations. At X-band frequency, vegetation distribution is one of the major sources for brightness temperature heterogeneity. As an initial investigation, we calculated the variance of vegetation water content within 1/8th degree boxes using 1/100th degree high-resolution data (results not shown). In this relatively simple comparison, the increased heterogeneity evident in the growing season compared to the winter period is clearly demonstrated. Areas adjacent to water bodies or containing rivers/lakes within their footprints will require careful discrimination to remove artefacts of pixel contamination. The removal of such features will be aided through the development of the GIS (discussed above) and integration of remote sensing information into that database.

2.4 Summary

Based on the research and analysis from SMEX02 and Oklahoma, we can conclude that:

- Compared to other microwave soil moisture retrieval algorithms, the LSMEM performs very well, which encourages further application of this physical model in retrieving soil moisture from space-borne platforms such as AMSR-E.
- Using intensive measurements from Oklahoma Mesonet, validation results during SGP99 and SMEX02 experiment, the retrieved soil moisture using the LSMEM over AMSR-E footprint scales (watersheds and study areas) is less than 3.5% volumetric soil moisture. This is within the stated accuracy of the AMSR-E plan.

Spatial heterogeneity is the main problem we need to solve for AMSR-E validation, as can be seen from the poorer comparisons between AMSR-E and the single SCAN soil moisture station.

3. FUTURE PLANNED ACTIVITIES

The following activities will be the focus of the next year:

1. Participation in the SMEX04 validation fieldwork, being planned for July in the NAME region (Arizona and northern Mexico (see http://hydrolab.arsusda.gov/smex04/ for more details)
2. Produce real-time AMSR-E simulated brightness temperatures with parameters collected from SMEX02 and SMEX03. This task will carry out the simulations at high spatial resolution and scale to the AMSR-E resolution to understand the scaling between the field-scale validation data and the AMSR-E resolution.
3. Initiate AMSR-E validation activities in Australia.

We have a unique opportunity to expand the AMSR-E validation by partnering with colleagues in Australia, who are carrying out field work that is useful to our validation activities.

3.1 AMSR-E Validation Studies in the Australian Arid and Semi-Arid Zones

Recent efforts to extend the estimation of soil moisture products to a truly global scale have focussed on the collection of sampling data in the semi-arid/arid environments of central Australia. In collaboration with investigators at the University of Melbourne (Dr. Jeff Walker), inter-platform and inter-algorithm comparisons of soil moisture content with *in-situ* data are currently being performed. The results from this analysis are expected to strengthen the robustness of existing calibrations, and offer insight into the dynamics of surface moisture responses in this region.

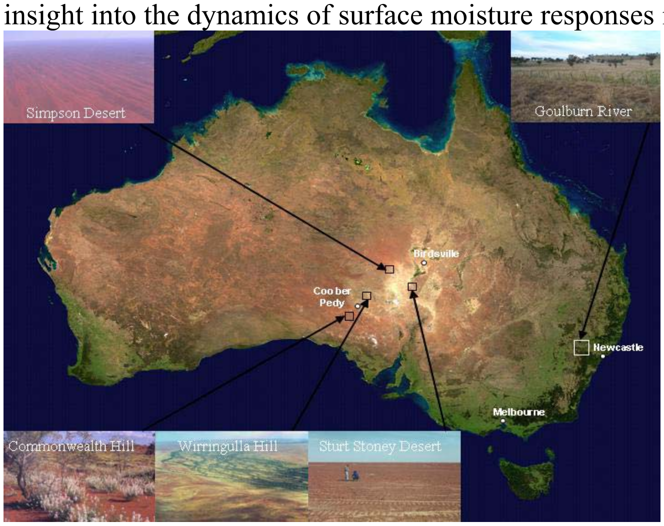


Figure 8. Sites within continental Australia offering facility for soil moisture evaluations over a number of different surface conditions.

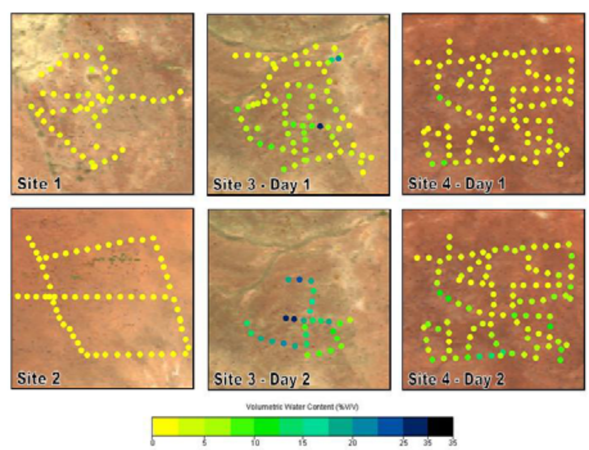


Figure 9. Sampling regime undertaken in South Australia during the 2003 field campaign. Dots represent sample locations, with colours depicting the relative soil moisture content.

Two three week long validation trips were undertaken during 2003. Ground measured near-surface soil moisture content is planned to be compared with both the beta version of the AMSR-E soil moisture product and LSMEM derived soil moisture. The *in-situ* moisture data collected at four sites (Figure 8) in the arid zone at two times of the year will compared against satellite derived estimates. Due to fortuitous timing of meteorological events, duplicate sampling at several sites under both dry and somewhat wetter conditions was undertaken (Figure 9). A time series comparison of the two soil moisture retrievals against rainfall records has shown some encouraging results, with both retrievals responding correctly to rainfall events. The relative homogeneity of the region makes it an ideal area in which to conduct a remote sensing validation program.

An additional study site located on the east coast of Australia offers a further opportunity to explore the behaviour of soil moisture over varying climatic and hydrological conditions. The study site for this project is the semi-arid Goulburn River catchment situated approximately 350km north-west of Sydney, on the east coast of Australia. The northern half of this catchment has predominantly low to moderate vegetation cover and is used for cropping and grazing, while the southern half of the catchment is more heavily vegetated, and includes a National Park. Soils in the northern section are predominantly basalt derivates while those in the south are sandstone derivatives. There are a total of 26 soil moisture monitoring sites, 8 stream gauging stations and 5 climate stations providing data for this study. Further details of this data can be found at http://www.civag.unimelb.edu.au/~jwalker/data/sasmas/.

4.0 Publication and Presentation

Gao, Huilin, Eric F. Wood, Matthias Drusch, Wade Crow, Thomas J. Jackson. 2004. Using a Microwave Emission Model to Estimate Soil Moisture from ESTAR Observations During SGP99, *J. Hydrometeor*. 5(1): 49-63.

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McCabe, M. F., Wood, E. F., Su, H., Gao, H. and Sheffield, J. (2003). "Remote sensing techniques for estimating large scale water balances." EOS Trans. AGU Suppl **84**(46).

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